and eastward to Lake Michigan, and by the following morning had covered the entire eastern section of the district. Warnings were ordered in advance of this condition in nearly all States threatened, with the exception of the central sections on the 25th. Local frosts occurred in the cranberry marshes of Wisconsin on several dates, and special warnings were issued in every case in advance of them.—*H. J. Cox, Professor and District Forecaster.*

DENVER FORECAST DISTRICT.*

[Wyoming, Colorado, Utah, New Mexico, and Arizona.]

The month presented no marked abnormal features. There was less than the average amount of precipitation generally thruout the district, and in Utah the mean temperature was somewhat below normal. Frost was confined to central and northern portions of the district, and at moderate elevations was generally light. Accurate and timely warnings were issued of frost that occurred in agricultural sections.—*F. H. Brandenburg, District Forecaster.*

SAN FRANCISCO FORECAST DISTRICT.†

[California and Nevada.]

The month was unusually cool in the Sacramento and San Joaquin valleys. Light rains occurred along the coast and showers and thunderstorms in the Sierra and Nevada on the 3d, 4th, and 5th. Light rain fell in the extreme northern portion of California on the 17th, 24th, and 27th, and light snow in the Sierra on the 28th. No frost or storm warnings were issued.—*G. H. Willson, Local Forecaster.*

PORTLAND, OREG., FORECAST DISTRICT.†

[Oregon, Washington, and Idaho.]

The month was unusually quiet and temperature and rainfall were nearly normal. Storm warnings were ordered on two dates for minor disturbances, and all frosts were successfully forecast.—*E. A. Beals, District Forecaster.*

RIVERS AND FLOODS.

There was little of interest during the month, and no floods occurred, except along the lower portion of the James River, in which the stages reached exceeded the flood line. Warnings were issued for the Ocmulgee and Oconee rivers in Georgia, the Wateree River in South Carolina, the James River in Virginia, and for the Binghamton district in New York.

No damage has been reported, except from the Binghamton district where the excessive rains caused washouts in the railroad beds and flooding by backwater from the sewers.

The highest and lowest water, mean stage, and monthly range at 202 river stations are given in Table VI. Hydrographs for typical points on seven principal rivers are shown on Chart I. The stations selected for charting are Keokuk, St. Louis, Memphis, Vicksburg, and New Orleans, on the Mississippi; Cincinnati and Cairo, on the Ohio; Nashville, on the Cumberland; Johnsonville, on the Tennessee; Kansas City, on the Missouri; Little Rock, on the Arkansas; and Shreveport, on the Red.—*H. C. Frankenfield, Professor of Meteorology.*

* Morning forecasts only; night forecasts made at Washington.
† Morning and night forecasts.

SPECIAL ARTICLES, NOTES, AND EXTRACTS.

ON ATMOSPHERIC CURRENTS AT VERY GREAT ALTITUDES.

By Prof. C. C. TROWBRIDGE. Contributed from the Phoenix Physical Laboratory, Columbia University, New York, N. Y., September 5, 1907.

In a recent abstract[1] the writer gave a brief summary of the results of a study of the luminous and long-enduring streaks or trains which are occasionally formed by large meteors. A complete discussion of the physical nature of these trains, with some additional facts recently determined, will appear shortly in the Astrophysical Journal.[2] The present paper relates to the atmospheric currents which are shown to exist in the extreme upper regions of the atmosphere of the earth by the observed drifting of these luminous trains.

The systematic observation and study of meteor trains is of much importance to meteorology because it is the only means by which the presence as well as the direction and velocity of atmospheric currents at very great altitudes above the surface of the earth can be determined. There has been little, if any, systematic work done in this direction heretofore. It is possible that one of the chief reasons for this fact is that the observations of meteor trains have been made almost entirely by astronomers, often in an incidental manner when engaged in other work; while the results obtained relating to the atmosphere and principally of interest to meteorologists have been published in astronomical journals and hence overlookt by those most interested in the subject.

Meteor trains are apparently self-luminous clouds which are usually deposited by large meteors, and particularly those that are swift moving, like the Leonids and Perseids. Astronomers who have made frequent meteor observations are familiar with the phenomenon, but few have taken up the matter further than to make records of the trains which they have seen. There are some notable exceptions. E. E. Barnard is the author of a paper entitled "Drifting meteor trains",[3] in which he gave the directions and rates of drift of five trains seen at Nashville, Tenn., having southeasterly and northeasterly drifts, and called attention to the importance of the observation of meteor-train drifts as a means of studying the movements of the atmosphere. W. F. Denning and A. S. Herschel have referred on many occasions to the drifts in England, and in a number of cases have calculated the altitude and in some the rate of drift of trains. H. A. Newton, C. A. Young, E. E. Barnard, and others have reported them in the United States from time to time. The astronomical journals contain records of train observations made in various countries all over the world.

The study of meteor trains was undertaken by the writer in order to find an explanation of the mysterious persistent luminosity of trains seen at night in the light of recent advances in physics, particularly relating to the conduction of electricity in gases, recombination of the gaseous ions, etc., and a solution of this problem seems promising. In the course of the work there has been found much valuable material relating to the movements of the upper currents in our atmosphere, which is brought together in the present paper.

Many of the trains studied are those which occurred from 1860 to 1870, when meteor observations were more numerous than usual, owing to the interest in the great Leonid showers of 1866, 1867, and 1868, but some of the most important records are of recent date. A number of bright trains were seen during the Leonid shower of 1901. In working up the records it was frequently necessary to determine the direction of the atmospheric drifts by reference to a celestial globe, for in many cases the movements of the trains with respect only to stars were found in the records.

The train drifts given in the present paper do not represent all the recorded observations on the subject, for, owing to the magnitude of the work, it has been possible for the writer to cover only a portion of the field, and the conclusions drawn are thus necessarily based on but a part of the available material. However, over sixty observations of meteor-train drifts have been found. These are given in Tables

[1] Physical Review, June, 1907, p. 524.
[2] Astrophysical Journal, XXVI, 2, Sept., 1907.
[3] Sidereal Messenger, I, 174, 1883; reprinted in 1891.

1–5. In order to retain the units used in the original records, the writer has exprest the altitude of trains and velocity of drift, in most cases, in miles rather than kilometers. The observations, when tabulated and studied, appear to bring out some new conclusions concerning the movements of the atmosphere at great altitudes. When further observations are made, and also all the past records are carefully studied, additional results will certainly be derived.

TABLE 1.—*Meteor-train drifts observed in Great Britain on November 14, 1866.*

No.	Place.	Time.	Drift toward—	Remarks.
9	Glasgow Observ'ry	12:32:50 a. m	S.	Visible about 5 minutes.
10*	Glasgow Observ'ry	12:40 a. m	E. by S.	Visible about 8 minutes.
11	London	1:07 a. m	NW. by W.	5° in 10 minutes.
12	Cardiff	1:08 a. m	E.	Several accounts.
14	Bath	1:50 a. m	E. or SE.	
16†	Nottingham	2:12 a. m	SW.?	"Drifted slowly along in a southwest current."
17	Kent	2:12:30 a. m	S.	Visible 6 minutes.
18	Glasgow Observ'ry	2:14 a. m	S.	
22	Kent	2:20 a. m	E.	Slightly eastward.
26	Edinburgh, etc	2:40 a. m	SE.	Train 61 to 67 miles altitude. Drifted 30° in 15 minutes.

* 50 miles altitude.
† A southwest current, in ordinary nautical phrase, drifts toward the southwest, but a southwest wind drifts toward the northeast.—EDITOR.

TABLE 2.—*Meteor-train drifts observed at various dates in Great Britain.*

No.	Place.	Date and hour.	Drift toward—	Remarks.
1	London	July 16, 1861, 11:30 p. m	S.	15° to 20° in 5 minutes.
62	England	Nov. 13, 1866, 2:14 a. m.	SE.	Drifted 30°.
42	Birmingham	Aug. 11, 1868, 12:08 a. m	SE.	
39	Southampton	Jan. 1, 1868, 1:27 a. m.	E.	
93	Dunbar	Aug. 15, 1870, 8:50 p. m.	SW.	Three accounts.
57*	Wales and Scotland	Nov. 6, 1869, 6:50 p. m.	NE.	Train from 45 to 27 miles altitude.
79	England	Oct. 30, 1891, 9:13 p. m.	NNE.	1° in 25 seconds.
80	Bridgewater, etc.	Aug. 26, 1894, 10:20 p. m	SE.	122 miles per hour at 54 miles altitude.
110†	Bristol	Oct. 27, 1900, 11:42 p. m.	SSE.	Visible for 13 minutes.
121*	Southampton	Jan. 7, 1856, 4:51 p. m.	SE.	Visible for 10 minutes.
67*	Torquay	Nov. 6, 1869, 6:45 p. m.	NE.	

* Train illuminated by sunlight. † Drifted 10° in 10 minutes.

TABLE 3.—*Meteor-train drifts observed at various dates and places.*

No.	Place.	Date and hour.	Drift toward—	Remarks.
86	Paris	Aug. 13, 1899, 12:53 a. m	SW.	14° in 20 minutes.
31*	Paris	June 13, 1867, 8:00 p. m	W.	Altitude 85 to 65 miles. Two observations.
30*	India, lat. 19° 55′ N.; long. 74° 55′ E.	Nov. 14, 1866	W.	Late in the evening.
97*	Asia Minor	June 18, 1845	W.	In twilight.
82	South Africa	Oct. 22, 1895, midnight	Upper S. Lower N.	Visible ½ hour.
128*	Tondern, Ger	Sept. 28, 1878, 7:30 p. m.	W.	Visible 1¼ hours.

* Probably illuminated by sunlight.

TABLE 4.—*Meteor-train drifts observed in the United States during the Leonid showers of 1866, 1867, and 1868.*

No.	Place.	Date and hour.	Drift toward—	Remarks.
29	New Haven, Conn.	Nov. 14, 1866, 2:11 a. m.	N.	125 miles per hour, 60 miles altitude; 3 stations.
32	Dartmouth, N. H.	Nov. 14, 1866, 1:57 a. m.	NW.	Visible 6 minutes.
33	Iowa City, Iowa	Nov. 14, 1867, 2:51 a. m.	SE.	7° in 4 minutes.
34	....do	Nov. 14, 1867, 2:56 a. m.	SE.	2° in 3 minutes.
35	....do	Nov. 14, 1867, 3:03 a. m.	SE.	1½° in 3 minutes.
36	....do	Nov. 14, 1867, 3:08 a. m.	S. by E.	11° in all.
36a	....do	Nov. 14, 1867, 3:08 a. m.	S. by E.	Time shortly after 3:08 a. m.
37	New Haven, Conn.	Nov. 14, 1867, 4:.. a. m.	E.	2° or 3° in 4 minutes.
38	Washington, D. C.	Nov. 14, 1867, 4:07:20 a. m.	N.	
44	New Haven, Conn.	Nov. 14, 1868, 1:12 a. m.	N. above 50 miles, S. at 50 miles	South drift 60 miles per hour.
48	Marathon, N. Y.	Nov. 14, 1868, 3:.. a. m.	N.	Visible several minutes.
49	Brunswick, Me.	Nov. 14, 1868, 3:51:30 a. m.	N.	Doubly observed.
50	New Haven, Conn.	Nov. 14, 1868, 5:06:45 a. m.	Upper S. Lower N.	Northward movement about 40 miles in all.
51	Bloomington, Ind.	Nov. 14, 1868, 5:25 a. m.	E.	Visible 10 minutes; drifted slowly.
52	Boston, Mass	Nov. 14, 1868, 5:30 a. m.	N.	Altitude 59 miles.

TABLE 5.—*Meteor-train drifts observed in North America before 1866 and after 1868.*

No.	Place.	Date and hour.	Drift toward—	Remarks.
7	New Haven, Conn.	Nov. 13, 1865, 4:.. a. m.	N.	North of zenith.
8	....do	....do	N.	South of zenith.
55*	Pennsylvania or New York.	Aug. 24, 1869	W.	Early evening.
56*	....do	Aug. 24, 1869, 7:25 p. m.	W.	Early evening.
61	Florida	Aug. 14, 1869	N.	Early morning.
67	Dubuque, Iowa	Aug. 23, 1878, 10:50 p. m	E.	
73	Dakota	Oct. 4, 1882, 7:50 p. m.	SW. or S.	Two accounts.
78*	Arizona	July 9, 1882, 7:50 p. m.	W.	Visible 10 minutes.
111†	Nashville, Tenn	Nov. 16, 1881, 7:.. p. m.	NE.	4° in 15 minutes.
112†	....do	Aug. 9, 1882, 9:.. p. m.	SE.	1° in 2 minutes.
113†	....do	Aug. 12, 1882, 3:.. a. m.	SE.	1° in 1 minute, 10 seconds.
114†	....do	Aug. 18, 1882, 10:30 p. m	NE.	1° in 3 minutes, 15 seconds.
115†	....do	Aug. 19, 1882, 1:30 a. m.	E.	1° in 32 seconds.
95†	....do	May 7, 1883, 3:10 a. m.	E. by S.	1° in 37 seconds.
75	Branch Co., Mich	Jan. 3, 1883, 7:00 p. m.	E.	
81	Chicago, Ill	Nov. 15, 1893, 2:50 a. m.	E.	7° in 30 minutes.
87	Boston, Mass	Nov. 14, 1901, 5:09 a. m.	NE.	2° in 15 minutes.
88†	Chicago, Ill	Nov. 14, 1901, 2:59 a. m.	E. or NE.	Two stations; 5° in 16 minutes.
90	South California	Nov. 15, 1901, 3:30 a. m.	N. by W.	
98	N. W. Ter., Canada	Nov. 15, 1901, 4:.. a. m.	N.	

* Train illuminated by sunlight. † Trains observed by E. E. Barnard.

The subjects discust in the present paper are arranged under the following seven chapters:

I. The meteor-train zone.
II. Superimposed air currents at great altitudes.
III. Probable connection between latitude and the predominating drift in the meteor-train zone.
IV. Explanation of illustrations, figs. 1–7.
V. Slow rate of fall of meteor trains.
VI. Meteor trains and laboratory experiments.
VII. Systematic observation of meteor trains.

I.—THE METEOR-TRAIN ZONE.

The altitude above the surface of the earth at which meteor trains occur when seen at night is between about 45 and 65 miles (72–104 kilometers). The height most favorable for longest visible duration appears to be about 55 miles (88 kilometers). Thirteen trains in the writer's catalog, carefully observed at two or more stations and their altitudes determined by triangulation by well-known astronomers, give a height of 54 miles for the mean altitude of the middle portions of the trains. It is the opinion of the writer that the density of the atmosphere prevailing at the altitude mentioned is favorable both for the formation and for the long duration of the persistent train. It would seem appropriate to call the region where these persistent luminous streaks of meteors seen at night occur, *the meteor-train zone.*

Trains of meteors which fall in daylight or twilight are not infrequently seen. They are apparently thin smoke trains illuminated by the light of the sun, and according to measurements occur as low as 25 miles altitude, but seldom above 50 miles, or between 40 and 80 kilometers. The trains seen at night, however, are usually, if not always, above 45 miles. It is thus seen that meteor trains occur at an altitude that is far above the regions which we are ordinarily familiar with. Various other means have been utilized to gain knowledge of the earth's atmosphere at considerable altitudes. As is well known, much has been accomplished recently by cloud observations and by means of kites and balloons provided with recording apparatus. The heights from which observations have been obtained by these means are as follows: The limit to which kites can be raised is about 4 miles, and while cloud observations have been made to a height of 8 miles, the usual region for cloud study is below this level; in a few cases, so-called ice clouds have been observed at considerably higher altitudes.[4] Balloons with recording meteorological apparatus have been sent to an altitude of about 15 miles, or 24 kilometers, but the usual limit for successful operation is below 12 miles, or 19 kilometers.

[4] The nocti-lucent clouds of midsummer are computed to be at 15 to 30 miles altitude.—EDITOR.

The distribution of volcanic dust over the earth's surface by air currents has served as a means of giving information concerning atmospheric drifts at altitudes of 25 and perhaps 30 miles, in but one notable instance only; i. e., the well-known facts of the drift of the volcanic dust of Krakatoa following the eruption of that volcano on August 26, 1883, from which it was concluded that at the equator there was a current in the upper atmosphere of from 70 to 80 miles per hour toward the west (the mean rate being 73 miles, or 117.4 kilometers), and at an altitude estimated to be about 25 miles, or 40 kilometers, above the earth's surface. This current was detected by the progressive change in the color of the sun as seen from different stations around the earth. The sun appeared bluish wherever it was partially screened by the thin cloud of volcanic dust [5] suspended in the atmosphere.

Summary of the observations in Tables 1–5.

The sixty-two meteor trains in Tables 1–5, observed chiefly in Great Britain and in the United States, show the directions of drift summarized below.

Trains seen at night.		Trains seen in daylight or twilight.	
Drift toward—	No. cases.	Drift toward—	No. cases.
North	10	North	0
Northeast	4	Northeast	1
East	12	East	0
Southeast	12	Southeast	1
South	6	South	0
Southwest	4	Southwest	0
West	0	West	7
Northwest	2	Northwest	0
Drift in two strata in different directions	3		
Total	53	Total	9

In 26 of these observations the rate of drift in degrees or miles was recorded. The greatest velocities observed were as follows:

In one case, 125 miles (200 kilometers) per hour northward drift, at over 60 miles (96.5 kilometers) altitude above New England, in the United States; and in another, 61 miles in 30 minutes, or 122 miles (196 kilometers) per hour, southeastward drift, at 54 miles (86.8 kilometers) altitude above England. Such rapid drifts appear to be not uncommon. In many cases the drift in degees was recorded, and if one degree is considered as equivalent to not less than one mile, as it would be for a drifting train at a distance of 57 miles, which is a conservative estimate, it is seen that a number of trains drifted in a current moving at a velocity of over 100 miles (160 kilometers) per hour.

It has been generally supposed that at great altitudes above the surface of the earth in the Northern Hemisphere there is an eastward drift, as has been suggested by Barnard. Among the facts demonstrated by this comparative study of meteor-train drifts are the following: First, that the drift toward the east predominates, which in the main is a confirmation of Barnard's view; and second, that the drift at altitudes of from 50 to 65 miles may be in any direction in northern United States and in England, and perhaps in the entire North Temperate Zone. That air currents may be in any direction at these great altitudes would seem to be an important fact bearing on the circulation of the earth's atmosphere, and also on the relation of currents in the meteor-train zone with those below.

It is a curious fact concerning the drift of nine daylight trains, or those seen by the reflected light of the sun, that seven were recorded as carried in a current toward the west, while none of those seen at night showed a westward drift; four of the latter, however, were southwest and two northwest. Owing to the fewness of the observations it is scarcely safe to draw any conclusions from this apparent westward drift, which probably took place in most cases in strata below an altitude of 50 miles. Moreover, the drift of meteor trains when noted by one observer can be recorded only with approximation, since merely one projection of the drift against the sky can be seen. A large number of such observations at different stations, however, when tabulated and studied would surely indicate some significant fact.

II.—SUPERIMPOSED AIR CURRENTS AT GREAT ALTITUDES.

There is almost conclusive evidence that there are at all times in the upper atmosphere superimposed currents of different velocities; usually those adjacent are in different directions in zones of from 5 to 10 miles in depth; in some cases in one zone there will be almost a calm, while directly above or below it there will be a current of considerable velocity.

It is the writer's opinion that there are always a number of these superimposed atmospheric strata with drifts in different directions. Many descriptions of trains record the appearance of several bends in the train, often referred to as "**M**'s" and "**N**'s" gradually formed after the train has lasted for some minutes. The arms (the straight parts of the letters), which correspond to the distances between bends in the train, are miles in extent; hence these curious distortions in the trains can arise from but one cause: namely, the variation in the velocity or direction of the currents of the atmosphere at different altitudes. In the case of one train, observed by H. A. Newton, three different drifts were recorded in opposite directions, one above the other, and in a number of others seen by various observers two drifts in opposite direction, all within ten miles difference in altitude; hence it is quite apparent that the higher atmosphere consists of a number of superimposed strata moving in different directions with various velocities. A typical train showing the forms described is that shown in fig. 3.

These superimposed currents may arise from differences in temperature perhaps due to the differences in radiation thruout the atmosphere, or they may accompany storms and the changes of atmospheric pressure near the surface of the earth. The same forces must be present in the upper atmosphere that are active near the surface of the earth. It would seem probable therefore that there are gradients of pressure, and hence unstable conditions, at various levels up to a height of 60 miles, sufficient to account for the observed movements in different strata at these great altitudes. The upper drifts would be thus similar to the well-known superimposed air currents in different directions near the earth. The fact that there are currents of high velocity in the upper atmosphere, and so often in different directions and probably changing in level, serves as good evidence that the composition of the atmosphere must be quite uniform up to heights corresponding to very low gas pressures.

III.—PROBABLE CONNECTION BETWEEN LATITUDE AND THE PREDOMINATING DRIFT IN THE METEOR-TRAIN ZONE.

Of 21 separate observations of the drift of trains in England and Scotland, in Tables 1 and 2, 15 show the presence of a current toward the southeast quarter of the compass, either east, southeast, or south; and on different dates 7 out of 12 drifts were southward or southeastward. But in the United States, 21 observations out of 32, in Tables 4 and 5, show a drift toward the northeast quarter of the compass, either north, northeast, or east; and on different dates or in widely different localities 13 out of 22 drifts were northward or northeastward. Of course, there are several questionable cases which might change these figures slightly, but the facts seem to indicate a difference in the drift of the atmosphere at about 55 miles height due to difference in latitude. Three daylight trains in Tables 4 and 5 were omitted in the above figures.

On November 14, 1866, in England and Scotland, the meteor-train zone current was directed toward the south or southeast

[5] This "dust" may have been minute spheres of vapor or ice.—EDITOR.

as shown by 6 or 7 out of 10 observations. On November 15, 1901, the drift in the western part of the United States appeared to be northward, while on November 14 in the middle and eastern portion it was toward the northeast.

While at present the observations are perhaps insufficient to show definitely a connection between latitude and the predominating atmospheric current in the meteor-train zone, yet the facts just mentioned seem to indicate that, passing northward thru the North Temperate Zone, the predominating current in the atmosphere at between 50 and 60 miles altitude is first northward, then northeastward, and finally, when latitude 50° to 60° is reached, southeastward. It seems not unlikely that the predominating drift may be partially dependent on local conditions which arise from the relative positions of continent and ocean in certain regions.

IV.—EXPLANATION OF ILLUSTRATIONS.

Caution must be exercised in the study of meteor-train drawings, because the pictures are necessarily often made hastily, and since trains from different view points may appear very different, owing to foreshortening; in many cases, however, it is evident that trains have been drawn with care.

Several drawings have been selected from a large number which show some interesting facts and in which also the foreshortening effects appear to be a minimum. In some of the illustrations the writer has added dotted lines and arrows to show the indicated atmospheric currents. Very exact copies of the original illustrations have not been attempted, but the drawings are as accurate as such sketches can be and serve their purpose perfectly.

The first of these drawings is fig. 1, *a, b, c, d,* a train seen by H. M. Dole, November 14, 1901, at 5:09 a. m., at Jamaica Plain (Boston), Mass. (No. 87 in Table 5). This drawing was sent to the writer by the observer. A similar illustration appears in Popular Astronomy, January, 1902. The northeasterly drift was apparently about 12 miles per hour, and the diffusion rate well observed. The train gradually expanded to 1.5° in width. The large size of the train is demonstrated by comparison with the familiar stars of Ursa Major which appear in the drawing. The train was visible about a quarter of an hour, and it is obvious that its exact position could readily be determined. The same train was observed at the Ladd Observatory, Providence, R. I., but its altitude has not been calculated.

Fig. 2 shows how rapidly a straight meteor train is distorted by atmospheric currents. These trains are many miles in length and hence the changes in form observed must not be accounted for by eddy currents which are set up by the rapid flight of the meteor thru the air. Eddy currents probably occur, but their sphere of influence can not exceed 100 or 200 meters. The train shown in fig. 2 was observed at Sidmouth and Cardiff, England, November 14, 1866, at 1:08 a. m., and was visible ten minutes (No. 12 in Table 1). The drawings appeared in the Reports of the British Association for the Advancement of Science, 1867, page 313.

Fig. 3 is a drawing of a meteor train seen over the Persian Gulf from Cape Jask, June 8, 1883, at 7:51 p. m. and observed by H. Harrison (not included in the tables). The drawing is taken from The Observatory.[6] The meteor fell vertically and it is evident that the changes in the form of the train noted at 7:57 and 8 o'clock are due to currents in nearly opposite directions in the atmosphere. The writer has added arrows and dotted lines to indicate the atmospheric movements. There were evidently in this case four superimposed currents, indicated in the drawing by small arrows, but the relative positions of the superimposed layers is somewhat uncertain from the illustration.

In fig. 4 the train shows two facts; first, the current in the atmosphere near the upper end of the train was very rapid, and second, below the sharp bend in the train there was a zone of comparative calm, at least in a direction perpendicular to the line of vision of the observer, then below this zone was a wind in the same direction as the one above. This meteor-train (No. 26 in Table 1) was observed by Backhouse at Sunderland, England, November 14, 1866, and is shown as it appeared at 2:42 a. m.[7] The meteor was seen at 2:40 a. m. from Edinburgh and Newcastle-upon-Tyne.

When trains appear broken like a straight staff bent over, similar to the train shown in fig. 4, or broken off, it is good evidence that at the level where the break occurs is the beginning of a zone in which there is a rapid current. Frequently a portion of the train will be observed to become detached and move off a number of degrees from the remaining portion of the train. Such a train was observed by Larkin in 1901 in California; the upper portion of it separated from and drifted some ten degrees from the lower. Fig. 5 shows a train which drifted in the same direction as the meteor's flight—*A*, as it first appeared; *B*, a few minutes later (No. 17 in Table 1).

Fig. 6 is a train carefully observed and discust at length by the late Prof. H. A. Newton of Yale, who carefully measured the height and drift of the train. The drawing is taken from the American Journal of Science, Vol. XLVII, page 399, Plate I. The train was visible forty-four minutes, and was 30 miles long at first, at a mean altitude of 54 miles, extending from 59 to 49 miles. The meteor was a Leonid observed at 1:12 a. m., November 14, 1868 (No. 44 in Table 4). At 1:14:10 the train was very distinct, but stars were seen thru it and it appeared as in (1). At 1:18:10 it appeared as in (2), moving sluggishly, and lookt like the nebula in Orion in a 12-inch glass. At 1:21:30 it was still a striking object, appearing as in (3). At 1:28 it had changed to the form of (4). According to Newton, the train had an appreciable breadth at first of about twenty minutes of arc, corresponding to a diameter of 1 mile, and the diameter was steadily increasing.

Newton's description of the drift (American Journal of Science, XLVII, 1869, page 408) is as follows:

> The southward motion of the lower end at Haverford, 80 miles from the cloud, was 25°, and at New Haven, 175 miles distant, was 8° or 10° during two-thirds of the period of visibility. These imply a motion of at least 40 miles, or about a mile per minute.
>
> We must therefore assume that just below an elevation of about 50 miles, there was a rapid north wind, which swept the lower portion of this cloud with it southward The wind may have come from one or two points east of north. Above this there was a south wind (or south-southeast), whose velocity may have equaled that of the lower north wind, tho it may also have been much less.
>
> By its downward motion the eastern end of the cloud was carried from the upper current into the lower, and strewn along into the horizontal cloud, seen at New Haven in the latter part of the period of visibility.

In closing his paper relating to this remarkable meteor, Professor Newton remarks: "What kind of matter it is which remains visible in cold upper air for three-fourths of an hour, until by gradual dissipation the light fades out, I leave for others to say." In his opinion the wavy motion and coiling of the train was due to the eddies produced by the rush of the meteor thru the air.

In fig. 7 a drawing of a train is shown which was sent to the writer by W. F. Denning of Bristol, England. The meteor appeared October 27, 1900, at 11:42 p. m. (No. 110 in Table 2). The train was visible thirteen minutes by using an opera glass. This train was selected to show how instantaneously the train assumes the motion of the atmosphere, the drift being almost at right-angles to the meteor's flight. Numerous similar cases have been reported.

V.—SLOW RATE OF FALL OF METEOR TRAINS.

It is evident that meteor trains fall but little owing to gravitational force, even assuming that they are partly composed of fine meteoric dust. This is shown by the calculations

[6] Vol. VI, 1883, p. 271.

[7] Report of the Luminous Meteor Committee, in the Report of the British Association for the Advancement of Science, 1867, p. 377.

Train of November 14, 1901, showing rapid expansion.

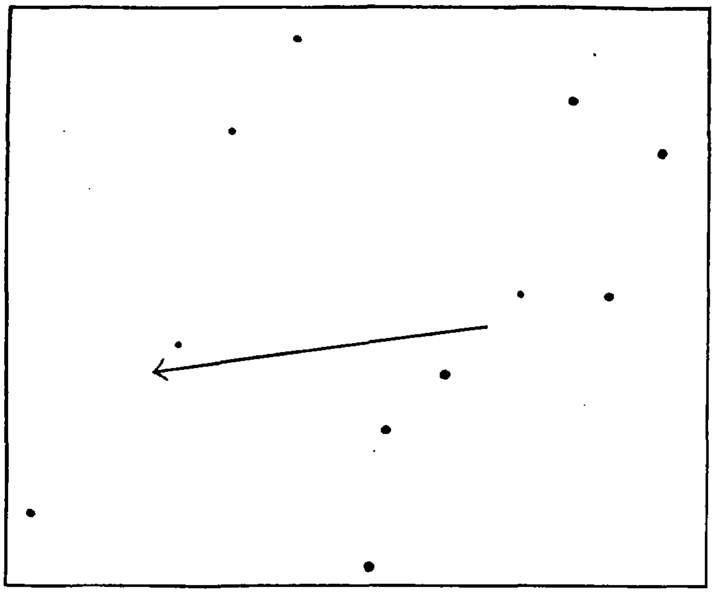

FIG. 1 *a*, at 5:09 a. m.

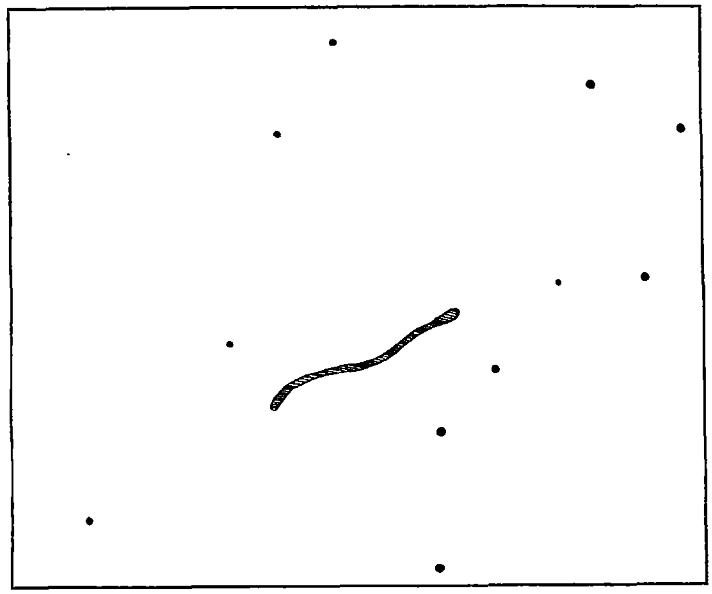

FIG. 1 *c*, at 5:17 a. m.

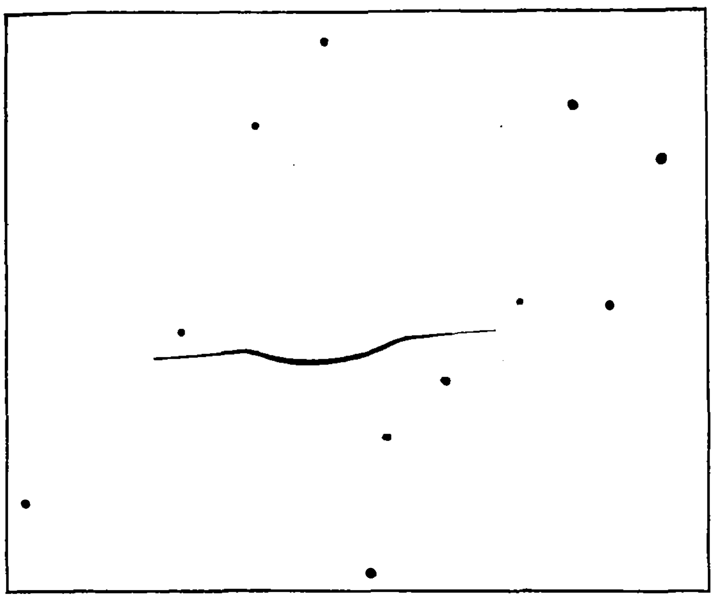

FIG. 1 *b*, at 5:12 a. m.

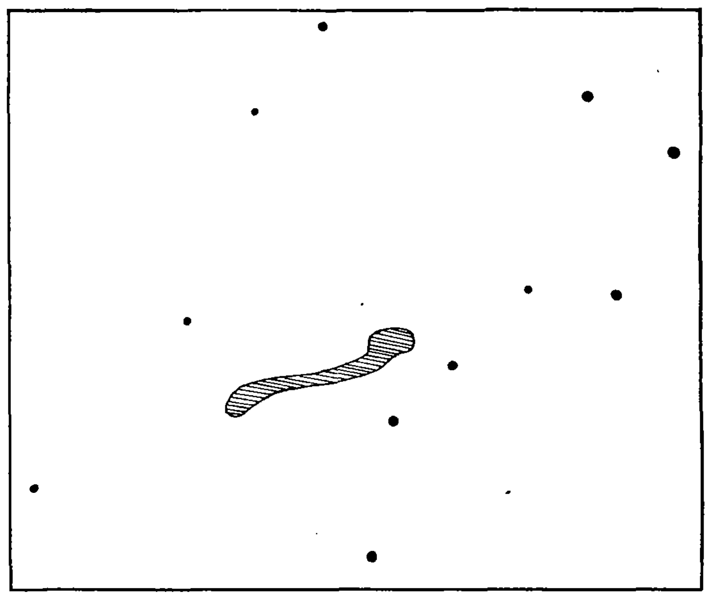

FIG. 1 *d*, at 5:25 a. m.

which have been made of the rate of fall of volcanic dust which drifted in the atmosphere after the eruption of Krakatoa in 1883. The Krakatoa Committee, appointed by the Royal Society of Great Britain, using a formula of Stokes, found that at an altitude of 15 miles particles .00003 inch (or .000075 centimeter) in diameter would fall at the very slow rate of 47 feet (15 meters) per day, a velocity agreeing approximately with the results of experiments performed by Professor Kiessling.[8] The solid particles of the meteor trains can certainly be no larger and are probably smaller than .00003 inch in diameter. While allowance must be made for the great altitude of the meteor train and the low density of the air, it should also be remembered that a descent of the luminous meteoric cloud, at even 16,000 times the above velocity or about the rate of 1 mile in ten minutes, would scarcely be observable. Moreover, the most carefully and longest observed trains have shown no descent, with one exception, that mentioned by Newton; therefore, if there is a downward movement observed in the case of any meteor train it must be due to a descending air current, and any descent due to gravitational force must be negligible. Trains can be safely regarded for meteorological purposes as clouds of gas or vapor, which change their positions and shapes by reason of their drift in the atmosphere, and increase in size by gas diffusion.

[8] The Eruption of Krakatoa, etc., p. 451.

VI.—METEOR TRAINS AND LABORATORY EXPERIMENTS.

Meteor trains seen at night are evidently self-luminous and are sometimes very bright, far too bright to be due to reflected light. They apparently have a spectrum that is composed of lines or narrow bands which indicates that they shine by their own light, and they are also considered self-luminous by astronomers who have observed them. The writer has been endeavoring to determine if the gas phosphorescence shown as the "afterglow" produced in a vacuum tube by the electrodeless ring discharge is the same phenomenon as the long-enduring train formed by meteors. Some interesting facts concerning this afterglow have already been determined. Some of these which relate to the present subject are very briefly stated as follows:

1. Experiments by the writer have resulted in the determin-

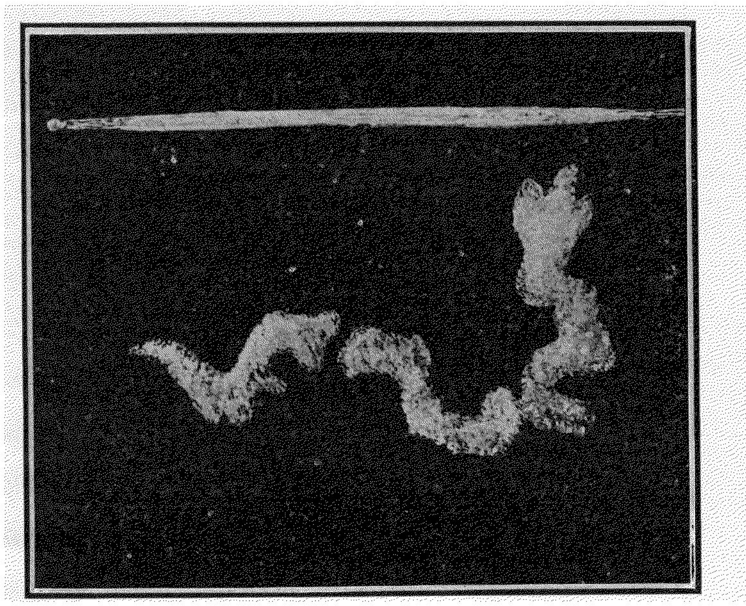

FIG. 2.—Train of November 14, 1866, 1:08 a. m., showing rapid distortions by air currents.

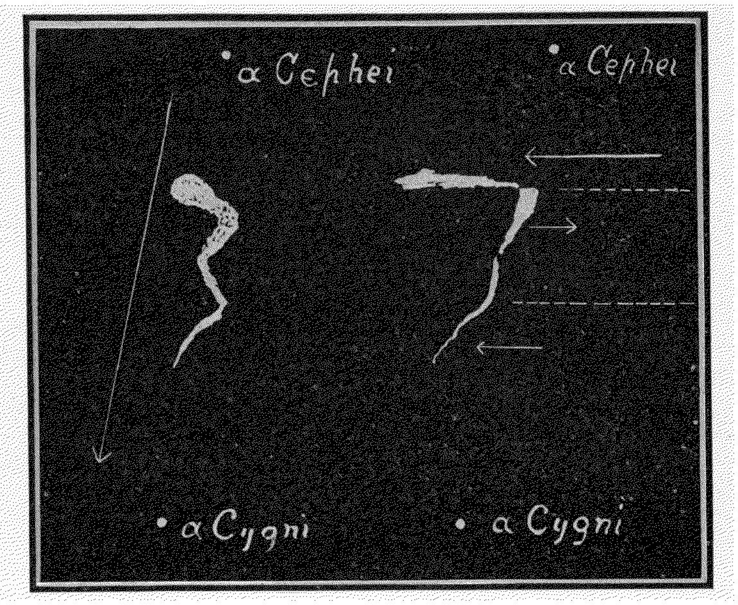

FIG. 4.—Train of November 14, 1866, 2:40 a. m., showing rapid current at the level of the upper portion of the train.

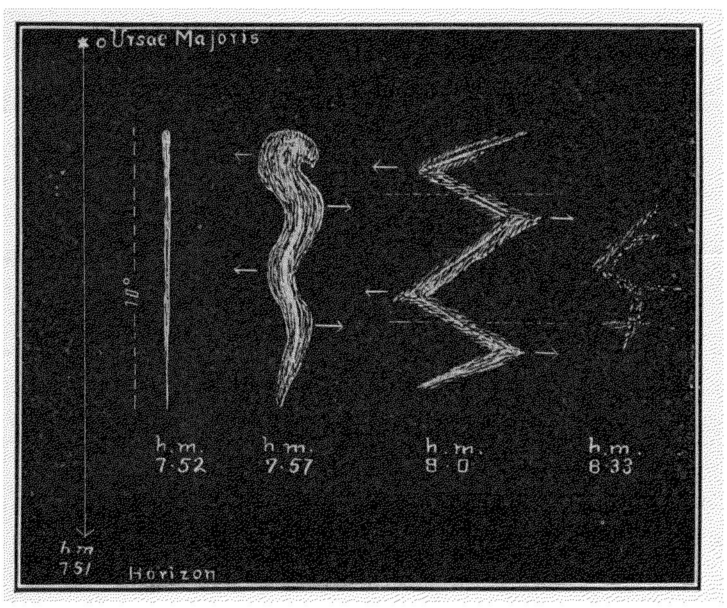

FIG. 3.—Train seen over the Persian Gulf, June 8, 1883, 7:51 p. m., showing the effect of currents in different directions at different altitudes.

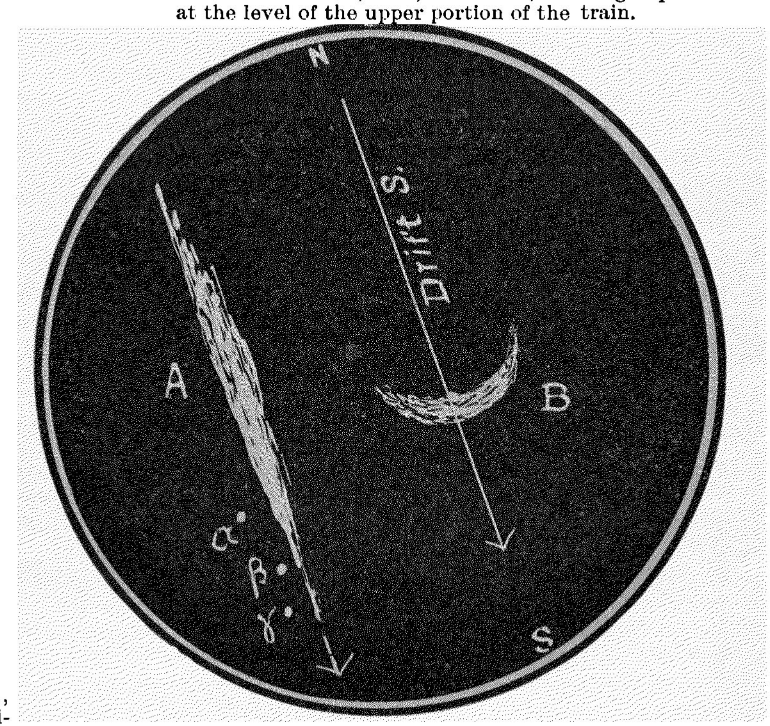

FIG. 5.—Train of November 14, 1866, 2:12:30 a. m., showing drift in same direction as flight of meteor.

ation of the law of decay or fading away of the afterglow in air at very low gas pressures. If the meteor train is a gas phosphorescence, which seems very likely, then its long-enduring luminosity is readily explained by applying that law to the fading light of the meteor train.

2. A study of the duration of the afterglow at various pressures shows that it occurs at a maximum at about 0.1 millimeter gas pressure, therefore, it is possible that pressures of the atmosphere at 55 miles above the earth may be not far from this value.

3. The color of meteor trains seen at night is usually yellow, green, or white. Twelve out of 27 proved to be green. The afterglow in the air is greenish yellow.

4. Meteor trains diffuse outward from the meteor track at a mean rate of about 100 meters per minute. The afterglow also diffuses with a velocity of the same order. Since diffusion is dependent on gas pressure and temperature, an experimental study of the subject may result in finding an approximate value for the pressure and temperature of the atmosphere where meteor trains are formed. While the evidence is by no means conclusive that meteor trains are the same as the afterglow produced in a vacuum tube, yet there are many points common to the two phenomena.

VII.—SYSTEMATIC OBSERVATIONS OF METEOR TRAINS.

It would appear as if the study of air currents at great altitudes was of sufficient importance to make worth while the inauguration of some plan for the systematic observation of meteor trains.

If, at a number of the observatories, watches are kept thruout the night at the times of the Perseid and Leonid showers,

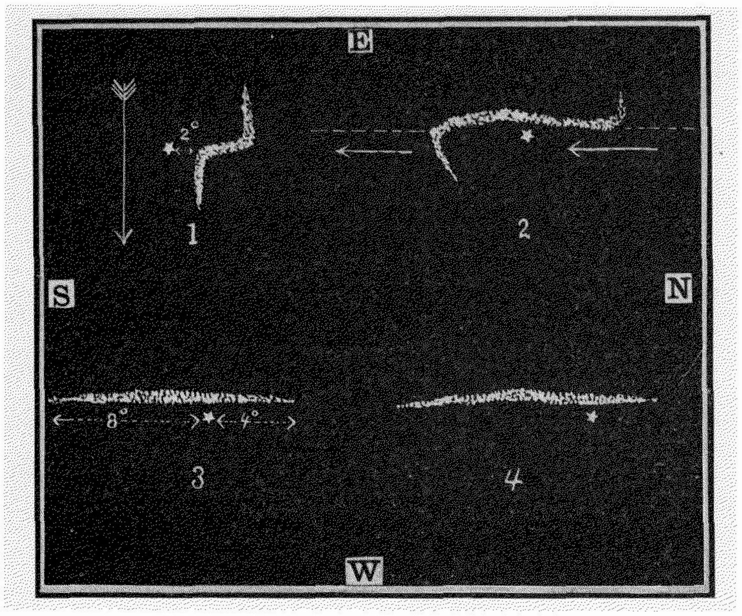

FIG. 6.—Train of November 14, 1868, 1:12 a. m., showing effect on vertical train of currents in opposite directions at different levels.

when streak-producing meteors are common, a few trains should be observed during each shower. Wherever there are two observatories separated by a distance suitable for a good base line, so that the trains can be triangulated and their altitudes determined, important results could be expected. Some form of small telescope for noting the drift among the stars would be the only instrument required. A train visible a few seconds to the naked eye would probably be visible a minute or more in a telescope, a fact demonstrated by Barnard, Denning, and others.

Meteor trains are by no means as rare as generally supposed. On one occasion nine separate trains were recorded by one observer in England using a small telescope during an evening of an ordinary Perseid shower in August.

It is hoped that when meteor trains are observed in the United States in future, the *exact position and change of position among the stars* may be noted at the time. In this way the altitude and drift can often be determined, for a conspicuous train is usually seen from one or more observatories and by reliable amateur meteor observers.

In 1901 several long-enduring trains were doubly observed in the United States, but the altitudes of these trains have not been worked out. It is much to be regretted that there is now no one taking the lead in collecting and calculating meteor data, to follow in the steps of the late Prof. Herbert A. Newton of Yale University, who accomplished so much in advancing the science of meteoric astronomy. It is an unusual opportunity for some one to take charge of such work in the United States. In Great Britain there are a score or more of careful observers, headed by Mr. W. F. Denning of Bristol, England, who is now the leading authority on the subject. The late Prof. A. S. Herschel, whose death has recently occurred, was also very active as a meteor observer, and the Luminous Meteor Committee of the British Astronomical Association, which reports annually its meteor observations, is also progressive.

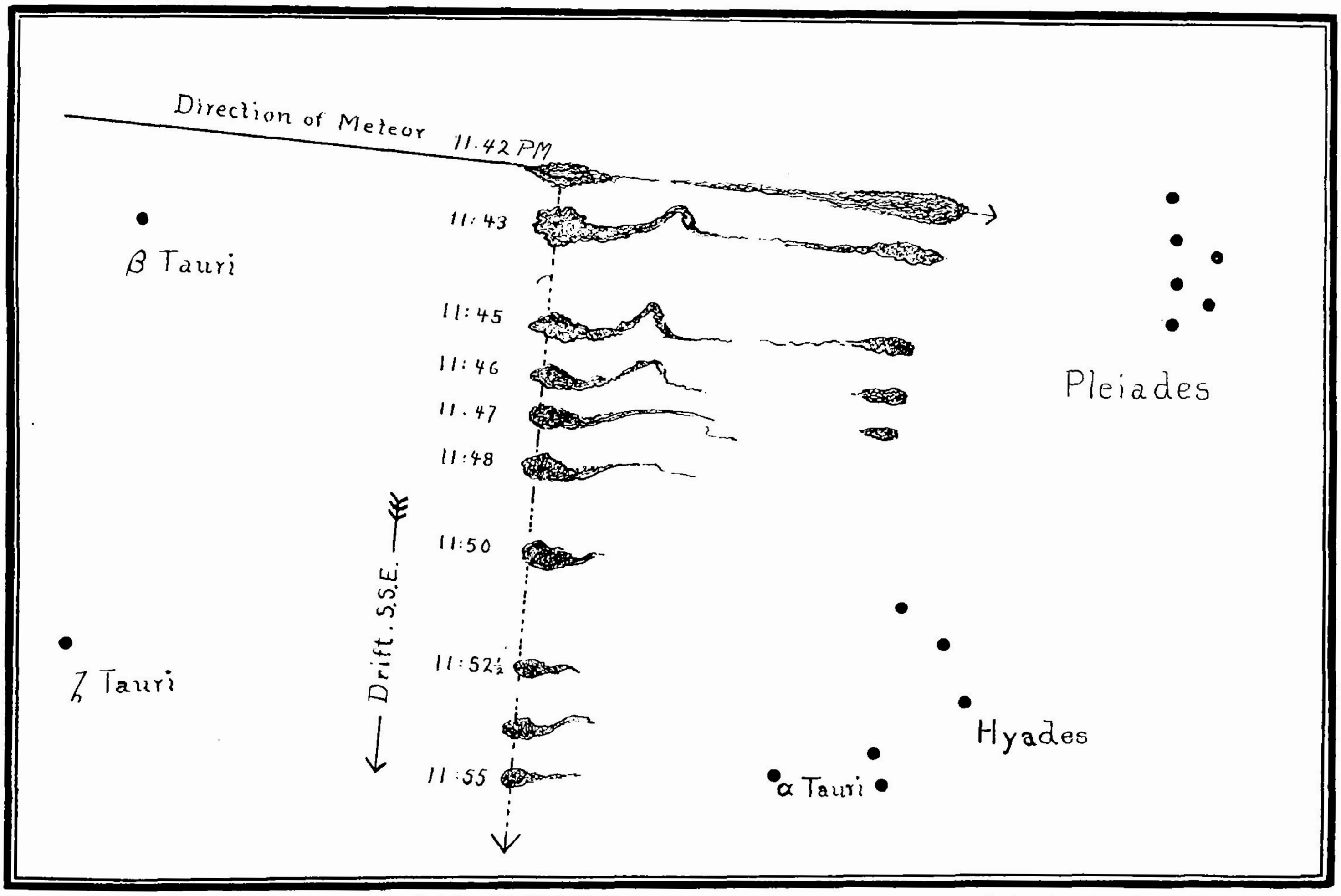

FIG. 7.—Train observed by W. F. Denning, October 27, 1900, 11:42 p. m., showing drift at right-angles to flight of meteor (copied from a drawing sent to the writer by the observer).

If the observations of meteor-train drifts were reported to one observer or to a specially appointed committee, whether the observations are made casually or from the result of a well organized plan, it would seem probable that in a few years enough drifts could be recorded to bring to light much concerning the movement of the higher atmosphere.

In closing I wish to thank the editorial staff for kindly furnishing me with some valuable data on meteor trains found in the files of the MONTHLY WEATHER REVIEW, and also Miss F. Harpham, of the astronomical computing staff at Columbia University, for assistance rendered on several occasions.

SPECTRAL FORMS IN MIST AND RAIN.

Talla Water is a lake from which Edinburgh derives its water. According to Dr. Hugh Robert Mill, director of the British rainfall organization (see British Rainfall, 1903, p. 49) "Talla is a classic land of rain". Sir Archibald Gilkie refers to it in his Scottish Reminiscences, thus:

> The Talla Valley is narrow and deep, the hills rising steeply from 1,000 to 1,400 feet above the flat alluvial trough at the bottom, which is about 900 feet above the sea. In the days of which I am speaking it was a lonely, sequestered glen, silent save for the bleat of the sheep or the bark of the dogs. In wet weather the wind drove up or down the defile, separating the rain into long vertical shafts, which chased each other like pale spectres. In the narrower tributary gorge of the Games-hope these ghost-like forms are even more marked; hence they are known in the district as the "white men of Games-hope".

STUDIES OF FROST AND ICE CRYSTALS.

BY WILSON A. BENTLEY. Dated Jericho, Vt., May 28, 1906. Revised July, 1907.

(Continued from August Review.)

The extreme difficulty of detaching and securing entire specimens of this type of frost for our purposes has prevented our photographing more than a very few of them. Those that the author succeeded with were, with but one exception, formed around frost nuclei upon windowpanes. For examples of this type of hoarfrost as formed in the open air, see No. 27 A. For additional mention of this type as found indoors on windowpanes, see No. 154 A, type WMD, in section 34, and Nos. 154 B and 161, type WSE, in section 35.

It is of much interest to find within this type of crystal, as within the other similar types heretofore mentioned, systems of air tubes and air inclusions. With the other points of similarity between them this serves to establish still more clearly the probability of the common origin of such air inclusions within both snow and frost crystals.

(17) HTG. Tabular snow crystals with hoarfrost additions.

A most important phase touching both snow and frost study is that relating to changes in habits of growth that may be induced by changes in environment. Very interesting opportunities are occasionally furnished for studying effects of this character, for on rare occasions snow crystals fall at nightfall, and hoarfrost crystal additions form in graft-like fashion upon them before they are modified by evaporation or by melting. This enables the student of crystallography to observe whether such hoarfrost additions as form on and grow outward from such fallen snow crystals conform to their own natural habits of growth, or to those of the fallen snow crystals. It would appear, from what the writer has learned from such few cases as have come under his own observation, that the hoarfrost additions, or grafts, grow and conform to hoarfrost types, rather than to snow-crystal types. Our photographs Nos. 96, 97, 98, and 99 show hoarfrost grafts or additions attached to freshly fallen snow crystals. It is remarkable that all the snow crystals of this series, as well as all the others having hoarfrost additions that have come under the writer's observation, are of a similar branch-like character.

It will be noted by consulting the photographs that in all but one the hoarfrost additions grew in a broad, solid, tabular fashion, in marked contrast to that of the frail, branch-like, snow crystals from which they started. Only in one case, that of No. 99 (which it will be noted portrays but a single segment, or branch-like ray added to the snow crystal), does the hoarfrost addition show a general near resemblance to the snow crystal from which it grew.

COLUMNAR HOARFROST.

Under this title are grouped all hoarfrost crystals that assume the forms of solid or hollow hexagonal columns, hollow hexagonal funnels, combinations of these to form compound crystals, and longitudinally bisected segments of columns and funnels.

(18) Type HCA. Columnar hoarfrost. Hollow columns.

Crystals of this type form in the shape of hollow hexagonal cylinder-like columns. This type of the column is commonly less slender and less elongated in the direction of its main axis than are those of the solid and of the solid fibrous types of the column to be described later. They vary in size from perhaps one-sixteenth to one-sixth of an inch in longer diameter. Many of them taper somewhat toward their bases. When formed in the open, they are essentially mild-weather types. They are most common to early autumn and late spring, and the hoarfrost that collects upon the plants and grasses during the so-called destructive frosts at those dates is almost invariably of this type. Hoarfrost deposits of this character form in the open during calm, clear nights when the surface air temperatures range from 56° to 40° at nightfall, and from 32° to 25° during the latter part of the night or early morning. Sometimes the cold becomes most intense and frost forms most rapidly in the early morning hours between daybreak and sunrise. Crystals of this HCA type rarely or never appear in relatively large numbers in the open simultaneously and associated with tabular hoarfrost crystals. During nights when tabular hoarfrost crystals predominate, this type, HCA, forms in general only on the bare ground and on the under sides of such objects as wood, leaves, straw, etc., that lie directly upon the bare earth, and not insulated from it.

In winter time the shorter and more perfect specimens of this type of frost are of relatively rare occurrence upon the shrubs, grasses, etc., in the open; but they frequently form in winter within relatively warm and inclosed, or partly inclosed, air chambers, as on the sides and roofs of cavities in the snow extending down to moist soil or water, on the under sides of water-trough covers, or of objects such as wood, embedded in the snow. In such confined situations they often grow for a long period of time, and hence attain much greater dimensions than in the open. Many of the individual crystals of this type exhibit but little variety, and a few specimens serve to carry an idea of all. It sometimes happens that they combine with hollow funnel-shaped crystals; funnel-shaped additions grow outward from the apices of the hollow columns and form compound crystals, presumably as a result of a change in atmospheric conditions. (See type HCE.)

Our photographs, Nos. 36 A, 36 B, 36 C, 36 D, and 36 E, quite correctly portray the aspect and general forms of such types of columnar hoarfrost crystals. Nos. 36 A and 36 E show them as collected in autumn and spring during destructive frosts upon grass blades and strawberry-plant leaves, respectively. Nos. 36 B and 36 C show these forms more highly magnified. No. 36 D pictures them as crystallized upon a cedar post.

(19) Type HCB. Columnar hoarfrost. Solid columns.

Hoarfrost crystals of this type grow in the form of the solid column. There are three varieties of the solid column. Some grow in the form of long, slender icy needles, others in a quasi fibroid form. One variety grows in the form of relatively short hexagonal columns, which greatly resemble crystals of type HCA, and in fact differ from them only in this,